PB-217 188

UNIVERSAL FACTORS IN AEROBIC BIOLOGICAL PURIFICATION

M. B. Ettinger

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

1957

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

PB 217 188 83
LIBRARY
SANITARY ENGINEERING CENTER
CINCINNATI, OHIO

UNIVERSAL FACTORS IN AEROBIC BIOLOGICAL PURIFICATION

M. B. Ettinger

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

Presented at the 30th Annual Meeting
of the
Central States Sewage and Industrial Wastes Association
June, 1957

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

Public Health Service

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

UNIVERSAL FACTORS IN AEROBIC BIOLOGICAL PURIFICATION

By: M. B. Ettinger

Robert A. Taft Sanitary Engineering Center
Public Health Service
U. S. Department of Health, Education, and Welfare
Cincinnati, Ohio

Natural stream self-purification is sometimes considered to be essentially different from oxidative waste treatment, such as is applied in an activated sludge plant. The activated sludge plant gives a percentage reduction of B.O.D. in a few hours which requires days in a stream. This is an artifact of operation and design rather than a manifestation of differences in biochemical oxidation rates.

Figure 1 presents schematically the series of transformations which take place in an isolated biological substrate supplied with oxygen continuously and held in the dark after a single feed. The system is assumed to contain a mixed biological population which may be a very small "seed", or a large mass of organisms such as the sludge in an activated sludge system. A liquid substrate containing food is also present. The food may be dissolved, suspended or in colloidal suspension. Some of the food is designated as common food, and by this is meant food which is readily used by organisms present. Some of the food is designated as exotic food and by this is meant food which is used with difficulty by the organisms present, sometimes after a long lag period in which it is not affected. Sometimes, the biological population may acclimate itself to an exotic food and use the material up rapidly, although some of the exotic foods are attacked slowly even by acclimated organisms(1).

Reproduced from best available copy.

In Figure 1, the ordinate axis represents either oxygen already used or the oxygen required to completely burn up either food or biological cell substance. As an example of how a chemical would be rated, a calculation is made below for ethyl alcohol.

$$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$$

$$\frac{\text{mol wt } 3O_2}{\text{mol wt } C_2H_5OH} = \frac{96}{46.07} = 2.08 \text{ p.p.m.}$$

The figure arrived at above is the oxygen equivalent to 1 p.p.m. of ethyl alcohol if the alcohol is completely burned up, either chemically or biochemically. Further calculations of the same kind have been presented by Placak and Ruchhoft[2].

Immediately after the food and the organisms in the substrate come in contact there may be rapid adsorption of some of the food involved. The total material adsorbed (A + A') is likely to be small in most cases and part of the exotic adsorbed chemicals may be released later if the biological solids in the system change in absorbing power or are reduced in amount. After the feed, the amount of biological material present will increase to a maximum as the result of growth and multiplication. Once the maximum amount of biolgical material is formed, further respiration will result in progressive decrease and destruction of solids. The amount of growth at time T_1 is represented by B'-B. After growth reaches its maximum, further aeration results in destruction of biological solids. Upon further aeration (time T_2 on Figure 1) the amount of solids present will equal those initially present; continued aeration now causes the amount of biological solids to decrease below their initial level.

As the system ages, the amount of oxygen which has been used (Y) increases. "L" and "L_t" are also shown on Figure 1. If the system studied is a sewage dilution of polluted river water the oxygen usage curve (Y) will trace out the usual curve for carbonaceous B.O.D.

If the system above were an activated sludge mixed liquor and the aeration were stopped at time T_1, then B' - B would represent the amount of sludge growth and presumably would represent excess sludge requiring disposal.

In both applied aerobic treatment and natural self-purification complete treatment is represented by the amount burned up (oxygen used). In an activated sludge plant, purification is accomplished in two ways:

(1) By absolute destruction (oxidation).

(2) By synthesis and adsorption followed by physical removal of this material along with the sludge.

An activated sludge plant (or a trickling filter) is accomplishing very fast removal of B.O.D. as compared to natural purification rates. However, in a mixed liquor aeration tank, sewage having 200 p.p.m. of B.O.D. is mixed with return sludge and the aerobic treatment is carried out in a system which may contain 2000 p.p.m. of B.O.D. with most of the B.O.D. present represented by the sludge. If the system is working well, the sludge can and will be separated. However, 200 p.p.m. of B.O.D. has been treated by applying air to 2000 p.p.m. of B.O.D. and the effluent is purified by oxidation of a load which is ten times as big as the load treated.

In terms of effluent quality, sludge growth may be a very important factor of purification. In a summary table showing the fate of certain groups of chemicals 24 hours after batch feeding to activated sludges, Placak and Ruchhoft[2] presented the data of Table 1.

TABLE I

Division of Feed Chemical Between Oxidation and Synthesis By Activated Sludge

Class	Percentage Oxidized		Percentage Converted To Organized Sludge
	Range	Mean	
Carbohydrates	5 to 25	13	65 to 85
Alcohols	24 to 38	30	52 to 66
Amino Acids	22 to 58	42	32 to 68
Organic Acid	30 to 80	50	10 to 60

Data of this type have been presented by many investigators such as Weston and Eckenfelder[3] and McKinney, et al[4].

The trickling filter offers two points at which B.O.D. may be converted to biological solids and withdrawn from the system. These are retention on the stone and the secondary sludge. There is an obvious limit to retention of B.O.D. by the rock so that secondary solids are the only point at which B.O.D. may be withdrawn in a trickling filter plant in the form of biological solids or biologically floculated solids over any very long period.

In a trickling filter system, the filter slime represents the biological accumulation which is being oxidized in a manner similar

to the activated sludge in an activated sludge system. The slime represents material collected from earlier loads treated and subjected to biological oxidation as long as it is retained on the filter bed.

Figure 2 shows the interaction between 1000 p.p.m. of activated sludge and a feed with an initial total oxygen demand of 389 p.p.m. estimated from data presented by Ruchhoft, et al[5]. It will be noted that in 24 hours of aeration only about 15% of the total organic load in the system was oxidized. The maximum amount of sludge was present about 5 hours after aeration was started, and during the remaining 19 hours of aeration about 45 p.p.m. of sludge was destroyed by catabolism. Supernatant B.O.D. has been estimated as unused food although this estimate is high because it includes biologically organized material which did not settle out of the supernatant samples.

Figure 3 presents a similar chart prepared from data presented previously by Ettinger[1] and shows oxidation of a soluble synthetic substrate given a very small initial innoculum of sewage. Examination of Figure 3 shows that more than 50% of the total oxidizable material initially present was burned up biologically during the second day. With the activated sludge system of Figure 2, only about 15% of the oxidizable material was actually oxidized during the 24-hour observation period.

It is quite apparent that activated sludge does not give super oxidation rates as compared to ordinary vigorous oxidations when the

total load present in the oxidation system is considered. Actually, the total organic load in the sludge aeration tank is composed largely of the living organisms making up the sludge and it is predictable that live sludge is harder to destroy than free food. Oxidation rates shown in Figure 3, for instance, are notably lower when the oxidizable material is present as biological solids.

The effect of a nutritional deficiency on the rate at which biological systems will carry out their purification is well known. If a nutritional deficiency, such as inadequate phosphorous, occurs in an activated sludge plant treating an industrial waste, the rate of purification which the plant can accomplish is limited. Lack of the nutritive element forces the system to reuse the scarce nutrient it contains again and again. New growth must await the release of the scarce nutrient held by the organisms which contain the total supply; such release occurs as the result of predation, lysis, phage induced lysis, and so on.

A nutritional deficiency does two things which retard purification:

(1) It limits purification rates by limiting the rate of growth of new cell substance.

(2) It precludes purification by synthesis of removable cellular material.

In some circumstances, avoiding the need for furnishing nutrients and disposing of excess sludge may warrant use of longer

process time, so that limited formation of new biological solids is not to be considered as a universal disadvantage. Protracted aeration, as was discussed earlier, can also control sludge production, even without a nutritional deficiency.

In discussing both the activated sludge process and the trickling filter, attention has been called to synthesis and sedimentation as an important part of the designed purification system. In the stream, sedimentation is frequently a major factor in freeing a stream of pollutants. Material may settle out directly, be converted to biological substance which settles out, or be converted to biological solids in the form of growth attached to solid objects in the stream, and finally organic pollutants may coalesce with silt and/or biological detritus and be carried to the bottom. Unlike the sewage disposal plant, the aerobic stream sometimes does not have a rational plan for handling bottom deposits. Ideally, the stream will carry out an aerobic digestion on the bottom with little or no accumulation. Sometimes a heavily loaded stream will digest bottom deposits anaerobically, giving off an occasional foul smelling, evil looking belch. In many cases however, the material will lie on the bottom in the form of polluted silts or bottom muds which digest slowly until they are washed out with the next river rise. A frequent cause of difficulty to water use is the first water of the stream flush out. The storage of pollutional material in stream beds is an important factor in improving water quality during low flow periods. If, however, it moves out in massive quantity when the river rises it can cause the least desirable water in the stream to occur at the time of the first flush out after a long dry spell.

In the consideration of the hypothetical oxidation model presented, photosynthesis was carefully ruled out by specifying that the system was held in the dark. In many streams photosynthesis leads to greatly supplemented oxygen resources during the day, accompanied by minimal oxygen resources at night. The sewage treatment plant also has a duirnal cycle since most plants receive about 2/3 of their flow and 80% of their organic load during a 12-hour period. The sewage disposal plant then has its excess resources at night and its most critical load during the day.

In some towns, there may be opportunity for advantageous smoothing of loads. For instance, some food processing operations might be arranged to give the bigger part of their load to the sewage treatment plant during low load hours. Where sewer rental charges based on flow volume and flow strength are being collected, consideration of lower charges for night flows may sometimes be appropriate. Such utility operation is routine with the power companies which give low night rates to the householder who heats his water electrically during the off-load period.

This discussion would be incomplete without an attempt to consider oxidative purification in a cyclically illuminated system. Such a system is considered schematically in Figure 4. Here the system is assumed to contain a mixed biological population which includes species of algae capable of growth in the system. The total biologically organized material is divided into two portions consisting of heterotrophic organisms which require organic food and oxygen for growth, and algal substance which uses sunlight as the source of energy for growth, and which synthesizes oxidizable organic material from carbon dioxide. Oxygen and carbon dioxide, or a source of carbon dioxide such as bicarbonate, are assumed to be continuously present.

The system presented (Figure 4) initially contains a readily available food supply for heterotrophs, and the system is put under observation at the start of a period of illumination. It is postulated that heterotrophic oxidation will initially predominate in the system. Next, there will be successive waves of algal synthesis related to illumination. This is inferred from the mode of illuminated algal metabolism as described by Odum[6]. It is further suggested that the bulk of the daily growth and catabolism wave caused by photosynthetic cycles will be represented by increase or decrease of the amount of algal substance present. This may not be strictly true since the amount of heterotrophic substance present could be affected also, but the assumption forms a reasonable basis for picturing what happens to the organic content of an aerobic cyclically illuminated system.

Both the algal substance and the organized cellular material of the heterotrophic system are likely to exert but little short time B.O.D. as long as they continue to live. Figure 4 indicates this in the nature of the oxidation curve. Even in an unilluminated sample such as is used on a 5-day B.O.D. test, algal cells may not reveal the magnitude of the organic accumulation which they represent.

In actual illuminated systems there are many variables which have not been included in the over-simplified model offered. These include distribution of illumination as a function of depth, separation of the algal cell material from the substrate, etc. These do not, however, impair the usefulness of the model offered as a key to understanding the behavior of systems in which illumination is important.

SUMMARY

The recurrent pattern of oxidative food usage by microorganisms and oxidative destruction of cell substance in unfed cultures has been described, and it has been noted that these phenomena are essentially similar in natural stream purification and in activated sludge and trickling filter systems. The universal effect of nutritional deficiencies on growth characteristics has been described and the effect of nutritional deficiencies on growth and oxidation analyzed. The sewage treatment plant has been noted to undergo a daily cycle with excess oxidation capacity at night because of reduced load. Algal photosynthesis has been analyzed in terms of its effect on oxidative purification processes.

1. Ettinger, M. B., "Biochemical Oxidation of Stream Pollutant Organics," Ind. and Eng. Chem., 48, 256-59 (1956).

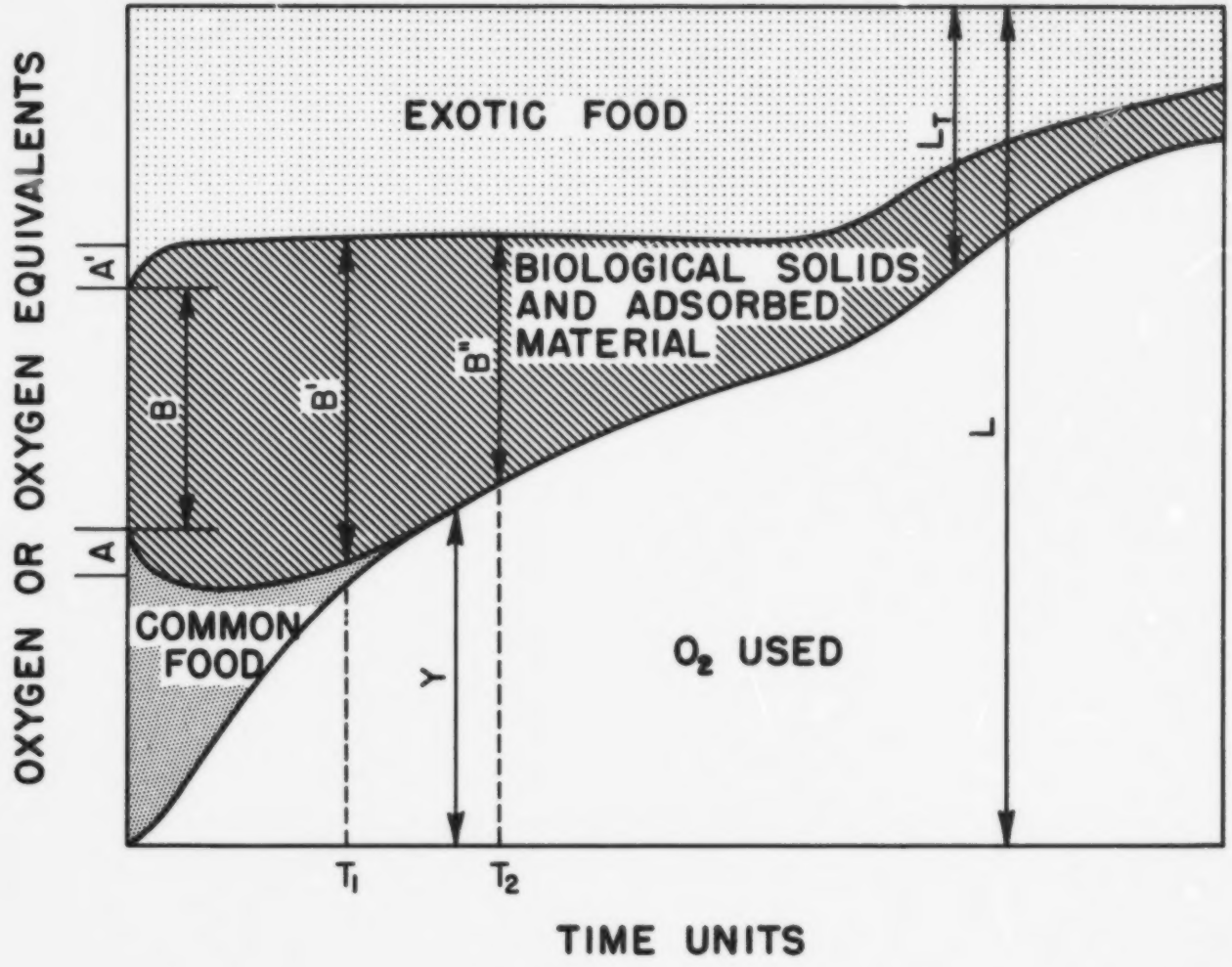
2. Placak, O. R., and Ruchhoft, C. C., "The Utilization of Organic Substrates by Activated Sludges." Public Health Reports, 62 697-716 (1947).

3. Weston, Ray F., and Eckenfelder, "Application of Biological Treatment to Industrial Wastes," Sew. and Ind. Wastes, 27, 802-19 (1957).

4. McKinney, Ross E., Tomlinson, Henry D., and Wilcox, Robert L., Sew. and Ind. Wastes, 28, 547-57 (1956).

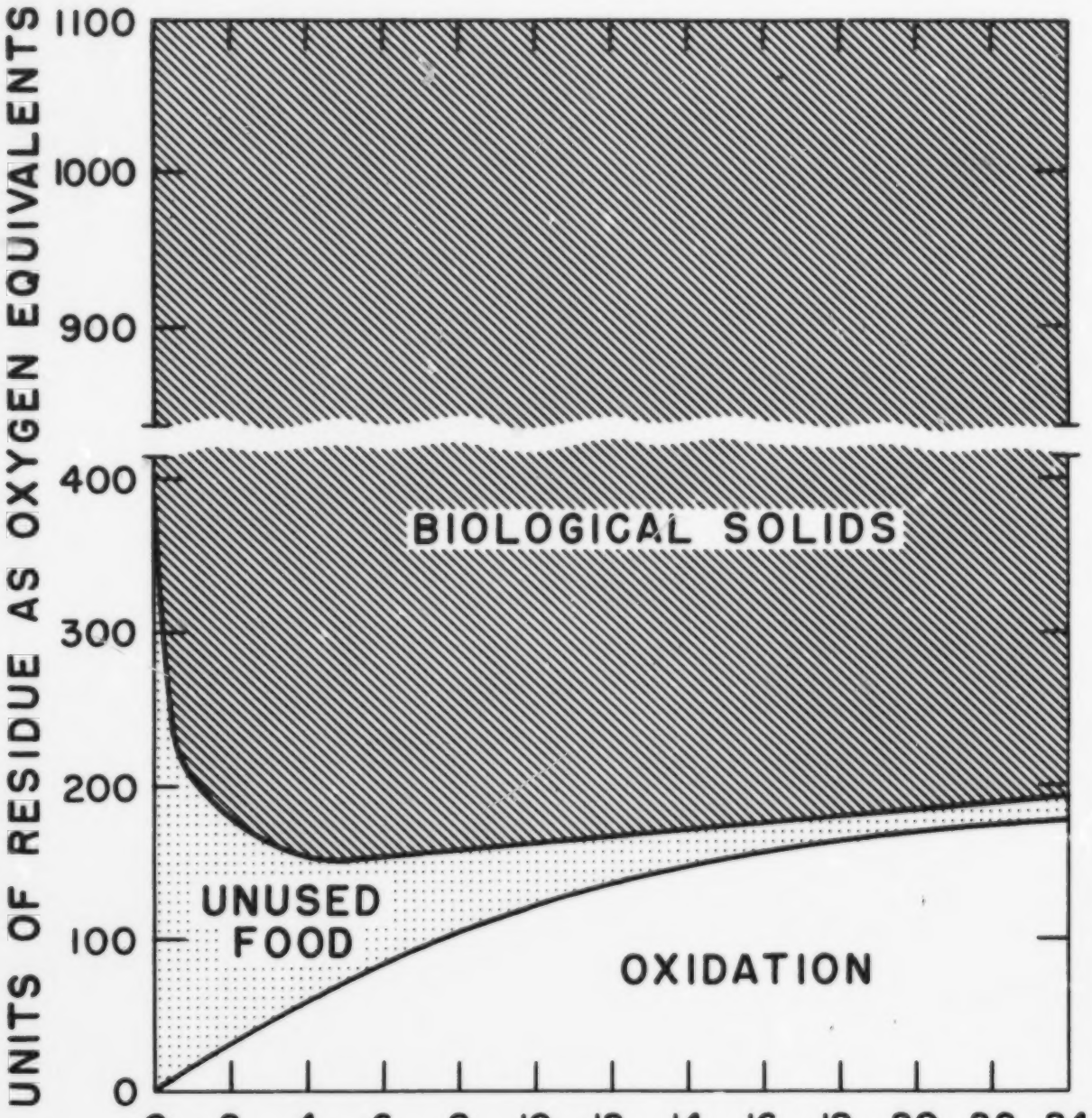
5. Ruchhoft, C. C., Butterfield, C. T., McNamee, P. D., and Wattie, Elsie, "Total Purification, Oxidation, Adsorption and Synthesis of Nutrient Substrates by Activated Sludge." Sewage Works Journal 11, 195-225 (1939).

6. Odum, Howard T., Limnology and Oceanography I, 102-17 (1956).



GENERALIZED REACTION OF A BIOLOGICAL SUBSTRATE TO A FEEDING

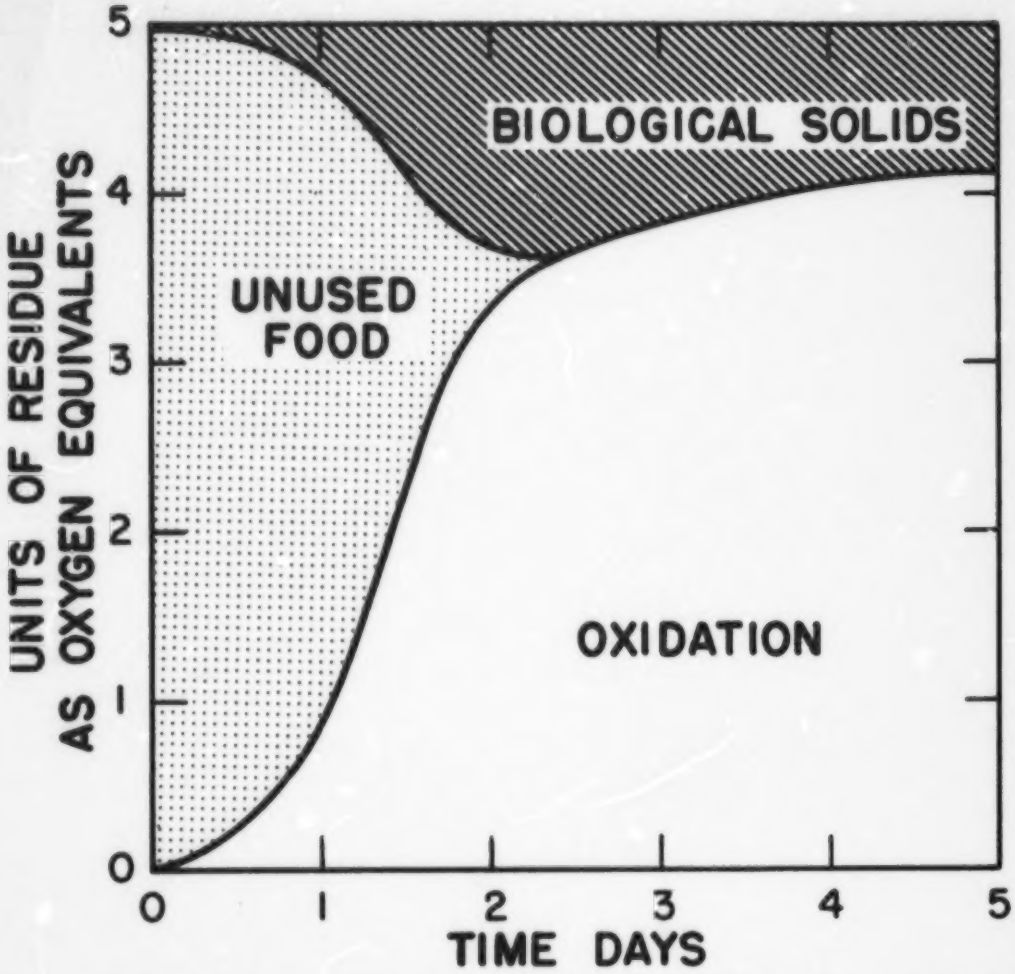
FIG. 1



ASSIMILATION OF FOOD BY A LABORATORY ACTIVATED SLUDGE

EST. FROM RUCHHOFT ET AL (5)

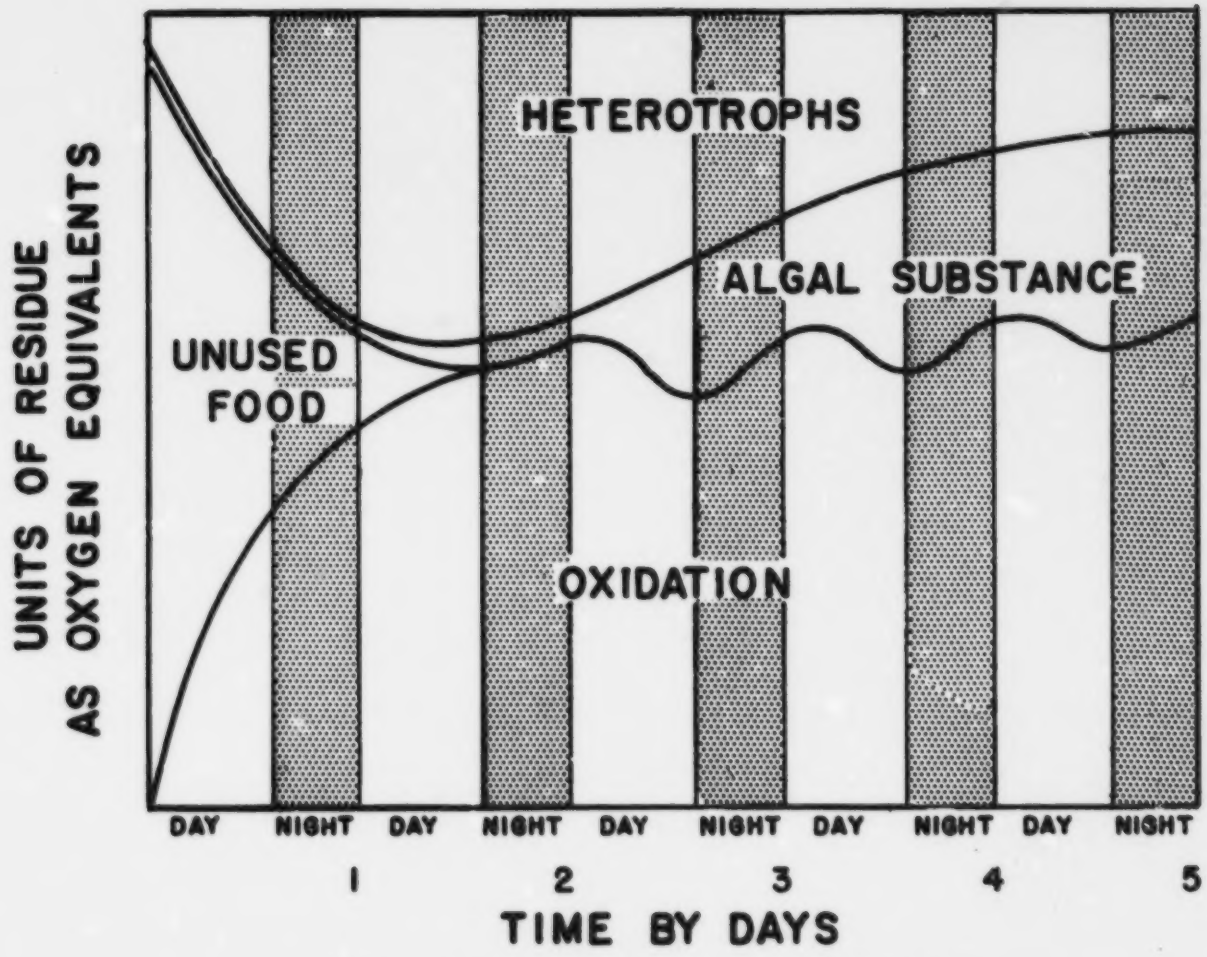
FIG. 2



ASSIMILATION OF A HEAVY FOOD DOSE BY A SMALL INNOCULUM

EST. FROM ETTINGER (1)

FIG. 3



EFFECT OF ALGAL GROWTH
ON OXIDATIVE STABILIZATION IN
A NATURALLY ILLUMINATED SYSTEM.

FIG. 4